AMERICAN MORTALITY STATISTICS AND THE MILLS-REINCKE PHENOMENON *

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In 1910, Sedgwick and MacNutt[1] published the results of their studies on the mortality statistics of several cities which had made a sudden change from a polluted to a pure water supply, and formulated what they termed the Mills-Reincke phenomenon and Hazen's theorem.

The city of Lawrence, Mass., installed a water filtration plant in 1893, and during the period immediately following, Hiram F. Mills, chief city engineer and a member of the Massachusetts State Board of Health, noted a marked reduction in the general death rate of the city, in addition to the decrease in the specific death rate from typhoid fever. At about the same time, the city of Hamburg, Germany, began the filtration of its water supply, and J. J. Reincke, health officer of Hamburg, emphasized in his annual reports that the reduction of the general death rate greatly exceeded the number of lives that could possibly have been saved from typhoid fever. Sedgwick and MacNutt, recognizing the sanitary significance of these observations, have applied to them the name of the 'Mills-Reincke phenomenon.'

At the end of a paper on the "Purification of Water for Domestic Use. American Practice," Hazen[2] discusses filtration from the standpoint of hygiene. After comparing the crude death rates of several cities which had made a radical change in their water supply with others similarly situated but which had made no such change, he expresses the opinion that, "where one death from typhoid fever has been avoided by the use of a better water, a certain number of deaths, probably two or three, from other causes have been avoided." This numerical expression, Sedgwick and MacNutt have termed "Hazen's theorem."

Both the Mills-Reincke phenomenon and Hazen's theorem have been widely quoted in public health literature, and attempts have been made to demonstrate their operation in various cities by showing a

* Received for publication January 20, 1917.

[1] Jour. Infect. Dis., 1910, 7, p. 489.

[2] Trans. Am. Soc. Civil Eng., Internat. Eng. Cong., 1905, 54, D, p. 151.

general reduction of the death rates in the years immediately following purification of their water supplies. The paper by Sedgwick and MacNutt contains a summary of the literature up to the date of its publication. I shall confine myself to a summary of the work done since then, and to particular information bearing on my own studies.

HISTORICAL REVIEW

Sedgwick and MacNutt[1] believe that they found abundant evidence of the occurrence of the phenomena under discussion in the mortality statistics of Hamburg, Germany; Lawrence and Lowell, Mass.; and Albany and Binghamton, N. Y. Binghamton showed irregular changes in its death rates following purification of its water supply, and during the second year following filtration there was a marked rise. Watertown, N. Y., in the 3 years following improvement in its water supply, showed an actual increase in the total death rate minus the typhoid component. This is explained on the basis of a relatively imperfect purification of the water.

Lederer[3] has compared the decrease in the typhoid death rates and the general death rates in 8 cities which had improved their water supply during the period 1900-1908. His figures included Providence, R. I.; St. Louis, Mo.; Youngstown, O.; Ithaca, N. Y.; Paducah, Ky.; Watertown and Binghamton, N. Y.; and Paterson, N. J. He found that the average reduction in the crude death rate was 3 times as great as would be expected from the reduction in typhoid mortality alone.

In a study of the relation of polluted water supplies to infant mortality, McLaughlin[4] found that cities with polluted water supplies have an unduly high death rate from diarrhea and enteritis in children, during the winter and spring months. He believes that the infected water is largely responsible. A brief study of the Mills-Reincke phenomenon is also included in his publication. Cincinnati, O., showed a marked reduction in the total number of deaths during the 3 years following the operation of its filters. Columbus, O., seemed to suffer an actual increase in the number of deaths during the years immediately following filtration. The average number of deaths in Philadelphia, Pa., for a period of 3 years before and after filtration is not appreciably less than can be accounted for by the saving of lives from typhoid fever. McLaughlin suggests that this may possibly be explained by the fact that filtered water was at first supplied to only one section of the city in 1906, and the filtered water area gradually extended until 1910. In the city of Pittsburgh, Pa., for every death from typhoid fever avoided, McLaughlin found but 1.1 deaths less from all other causes. This is considerably less than Hazen's theorem suggests.

The water supply of Chicago for many years was contaminated by sewage from the Chicago River entering Lake Michigan and finding its way to the water works intakes. The result was a notoriously high typhoid fever death rate with occasional explosive epidemics. In 1900, most of this sewage was diverted into the Drainage Canal, built for the purpose and draining away from the lake. Soper, Watson and Martin[5] in their short discussion of the effect of opening the Drainage Canal on the mortality of Chicago, conclude

[3] Am. Jour. Pub. Hyg., 1910, 20, p. 295.
[4] Pub. Health Rep., 1912, 27, pp. 579-612.
[5] Report to Chicago Real Estate Board on Disposal of Sewage and Protection of Water Supply of Chicago, Ill., 1915.

that according to their figures there has been no marked fall in the general death rate following improvement in the water supply. Those specific diseases which showed a decrease seemed to be in no apparent relation to the water supply.

A comparison of the mortality statistics of Cincinnati, O., for a 3 year period before and after filtration was made by Landis.[6] This shows that the deaths from diarrheal diseases in children under 2 years, including inanition and convulsions, for the 3 years before filtration was 133 per 100,000 of population; for the same period following filtration, the rate was 98 per 100,000 of population. During the 3 years following efficient milk inspection, there was a further drop in the rate to 76 per 100,000. These statistics illustrate the danger of attributing a marked fall in mortality to any one factor. The death rate from acute and chronic nephritis during a 5 year period before filtration was 123 per 100,000, while for a similar period following filtration it was 136 per 100,000. The average death rates from diseases of the circulatory system during the same periods was 203 and 228 respectively, per 100,000.

Fuller[7] also discusses the experience of Cincinnati and gives a table showing the death rates for the same period. He finds that there are irregular but quite striking reductions in mortality from specific diseases other than typhoid fever, as well as in the total death rate.

In the report of the board of health of Columbus, O., for 1913, Louis Kahn publishes the results of his calculations which show that the average total death rate from 1901 to 1908 was 15.4, and from 1908 to 1913, 14.6 per 1000 of population, indicating that there has been a decrease in the general death rate as well as the typhoid fever rate since their filtration plant went into operation.

The report of the department of health of Pittsburgh for 1911 contains the death rates for the unfiltered area as compared with the filtered area, as indicated in Table 1.

TABLE 1

COMPARISON OF DEATH RATES IN PITTSBURGH OF FILTERED AND UNFILTERED WATER AREAS

	Filtered Water Area (Old City and South Side)	Unfiltered Water Area (North Side)
1909	12.6	30.9
1910	13.1	47.3
1911*	11.2	45.1

* The total number of deaths for the filtered water area during 1911 was 46; for the unfiltered area, 61.

The explanation for the reduction in mortality from the so-called 'water-borne diseases' is apparent, and this no doubt accounts for the greater part of the reduction in the general death rate following purification of a water supply. McLaughlin[4] thinks that the greatest measure of reduction is due to a decrease in mortality from diarrhea and enteritis in children, while Landis[6] is of the opinion that efficient food inspection is equally effective. No satisfactory explanation has been advanced for the mortality reduction in other diseases not thought to be to any extent water-borne, such as pneumonia, nephritis, cardiac diseases and tuberculosis. In the discussion of Hazen's paper, Jordan[2]

[6] Annual Report of Dept. of Health, Cincinnati, O., 1914.
[7] Sewage Disposal, 1912.

pointed out that owing to errors in diagnosis, deaths from typhoid fever are sometimes reported as death from malaria and typhomalaria,[8] and that at least a part of the reduction noted following the purification of a water supply is due to the disappearance of these deaths from the statistics. In a recent paper, Jordan[8] again draws attention to the fact that at least a part of the decrease in the non-typhoid mortality is due to the reporting of typhoid deaths under such heads as malaria or typhomalaria. He also suggests that it might be worth while to investigate more closely the relationship between deaths from the sequelae of typhoid fever and the Mills-Reincke phenomenon and Hazen's theorem. The problem is extremely complicated because the number of deaths avoided from typhoid fever, and the number of lives saved from water-borne diseases are but 2 factors in a situation involving a multiplicity of operative factors. The difficulty will be in assigning to each its proper significance, and there is danger of emphasizing some one factor to the exclusion of others equally important.

Dublin,[9] in an analysis of the causes of death in 54 of 1428 recovered cases of typhoid fever, found that 38.9% died of tuberculosis; 14.8% of diseases of the heart; 7.4% of pneumonia; and 7.5% of nephritis. The greatest number of deaths was found to occur within the first 2 years after recovery from typhoid fever. Comparison with tables of life expectancy showed that within the first year the actual mortality was about 3 times the expected, and in the second year more than double the expected. On the bases of this double mortality in the 3 years following recovery from typhoid fever, Dublin has estimated that 7781 deaths are annually attributable to the sequelae of this disease throughout the United States. These figures are based upon a small number of cases occurring among a selected class. Therefore, broad general conclusions based upon them are hardly justified. On the other hand, the cases were selected with great care to insure accuracy of diagnosis, and the records are complete.

A recent report[10] contains a chart of the death rates per 100,000 of population from certain important causes in the Registration Area during the years 1900-1914. Tuberculosis (all forms) has a curve almost identical with pneumonia (all forms) from 1900 to 1906. In the following years the curves are similar, both showing a sharp downward tendency, but pneumonia has 2 sharp peaks in 1907 and 1910,

[8] Jour. Am. Med. Assn., 1916, 66, p. 467.
[9] Am. Jour. Pub. Health, 1915, 5, p. 20.
[10] Bureau of the U. S. Census, Mortality Statistics, 1914, p. 23.

which do not appear in tuberculosis. The curves for organic heart diseases and nephritis have similar outlines and run almost parallel. Diarrhea and enteritis of children resembles in outline the curves for tuberculosis and pneumonia, but the sharp peaks of the latter are missing. The curve for typhoid fever slopes gradually downward, the

TABLE 2

TOTAL DEATH RATES PER THOUSAND POPULATION DURING THE YEARS 1901-1914

City	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Boston........	19.9	19.1	18.3	18.3	18.5	18.6	18.6	18.3	16.8	17.2	17.1	16.4	16.4	16.1
New York......	19.9	18.6	18.0	20.1	18.4	18.3	18.3	16.3	16.0	16.0	15.2	14.5	14.3	14.1
Cincinnati.....	19.5	17.9	18.6	20.6	18.9	20.4	18.1	18.0	16.5	17.4	16.5	16.6	16.9	16.0
Columbus......	14.1	15.5	16.3	16.1	14.9	15.3	15.5	15.2	14.0	15.4	14.3	14.4	15.3	14.8
Philadelphia...	18.0	17.5	18.7	18.7	17.6	19.1	18.6	17.3	16.4	17.4	16.6	15.3	15.7	16.1
Pittsburgh*....	18.8	20.9	20.8	19.2	19.9	19.9	19.3	17.3	15.8	17.9	14.9	15.9	17.1	15.7

* As now constituted.

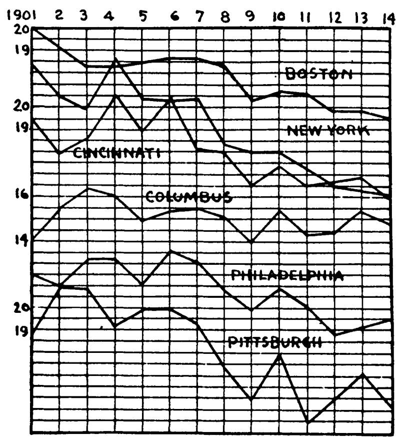

Chart 1. Total death rates per thousand of population. Plotted from Table 2.

limits being between 15 and 35 per 100,000, and shows no sharp irregularities. The year of highest mortality, 1900, is followed by a marked drop in the rates from tuberculosis, pneumonia, diarrhea and enteritis, in 1902. But, in 1904, tuberculosis and pneumonia show a sharp rise, while diarrhea and enteritis show a similar peak 2 years later, in 1906. Pneumonia, heart diseases, diarrhea and enteritis show well defined

peaks in 1907, a year following a slight rise in the typhoid fever rate. The fluctuations in the diarrhea and enteritis rate are more marked than those of typhoid, but it is noticeable that, in general outline, the 2 curves resemble each other. In typhoid fever, there is the beginning of a rise in 1901, lasting for 2 years. In the case of diarrhea and enteritis, this rise begins where the typhoid rise ceases and reaches its maximum 3 years later, in 1906.

Before proceeding with my studies, I sought to determine to what extent clinical data and experience support the facts cited regarding the sequelae of typhoid fever.

TUBERCULOSIS

Woodruff[11] studied the effect of typhoid fever on tuberculosis by making inquiries of tuberculosis workers and by comparing the curves of tuberculosis and typhoid fever death rates in different countries. The percentage of patients suffering from tuberculosis giving a history of previous typhoid fever varied from 3.6 to 17.06%. Matson in reply to Woodruff's questionnaire estimated that tuberculosis was a direct sequel to typhoid in 10% of all his cases. In the countries for which the death rates of tuberculosis and typhoid fever were compared, the curve showed that where a drop in the typhoid fever mortality occurred, this was paralleled by a drop in the tuberculosis mortality: The data for the large cities do not show such close similarity, and the explanation given is that the nonresident deaths are responsible for the discrepancy. A remarkable reduction in the incidence of tuberculosis following a drop in the typhoid fever rate was found in the experience of the British Army in India. The figures for the U. S. Army also show that with a fall in the typhoid fever rate there has been a coincident reduction in tuberculosis. The health authorities of both New York and Pennsylvania reported that typhoid and tuberculosis had markedly declined in their respective states in recent years and at about the same rate. Woodruff believed that the facts brought out by his figures serve to explain the fall in the death rate from tuberculosis following purification of public water supplies observed by Sedgwick and MacNutt,[12] namely, that not only are a certain number of deaths from typhoid prevented, but that the incidence of tuberculosis is reduced by removing one of the predisposing causes. Of interest in this connection may be cited the experiments of Brown, Petroff and Heise.[13] They studied the results of constant contamination of Saranac Lake River with sewage from the village of Saranac Lake, N. Y. Ninety % of cases of open tuberculosis of the lungs excrete viable tubercle bacilli in the feces and one would naturally expect that a stream contaminated with sewage from a tuberculous community would contain living tubercle bacilli. They found that guinea-pigs could be infected with water taken at a distance varying from the sewer's mouth to at least 3 miles down stream on cloudy days, but on sunny days the acid-fast organisms obtained 2.9 miles down stream produced no tuberculosis.

In commenting on the effect of antityphoid vaccination in the U. S. Army, Shimer[14] says that this practice has not increased other diseases, but that

[11] Am. Med., 1914, 20, p. 17; Science, N. S., 1914, 39. p. 173.
[12] Tuberculosis in Massachusetts, 1908, p. 181.
[13] Am. Jour. Pub. Health, 1916, 6, p. 1148
[14] Jour. Indiana Med. Assn., 1914, 7, p. 282.

tuberculosis, the disease suspected of being on the increase, has actually decreased in the army since 1908.

McCrae[15] thinks that it is difficult to determine by statistics whether typhoid fever predisposes to a subsequent attack of tuberculosis or whether tuberculosis confers a relative immunity against typhoid. Tuberculosis may follow typhoid fever, but in the majority of cases, it is probable that the diagnosis was wrong and the condition was tuberculous from the beginning. Acute miliary tuberculosis is not infrequently mistaken for typhoid fever.

THE CIRCULATORY SYSTEM

There are no changes in the heart and blood vessels peculiar to typhoid fever. The cardiovascular complications and sequelae in the cases coming to Osler's clinic for 14 years have been studied by Thayer,[16] who also reviewed the literature on the subject. Endocarditis is a rare complication, only 11 cases being reported among 2000 autopsies at Munich, while but 3 were found in nearly 100 autopsies at the Johns Hopkins Hospital. Thayer quotes Landouzy and Siredey as of the opinion that next to articular rheumatism, typhoid fever appears to be accompanied by more cardiovascular complications than any of the other infectious diseases.

Thayer himself was able to examine 183 of 1400 patients discharged from the typhoid fever wards of the Johns Hopkins Hospital over a period of 13 years. He found that the average systolic blood pressure was higher in these old typhoids than in healthy controls. The average size of the heart was greater than in the same cases at the time of admission to the hospital. Cardiac murmurs were heard with greater frequency than during the attack. Although the series of cases is small, there can be no doubt that it indicates that persons recovering from typhoid fever are more likely to suffer from cardiac diseases than normal persons, and, other conditions being equal, are further on the way toward arteriosclerosis.

In a study of 793 cases of typhoid fever in von Jaksch's clinic at Prague during 1889-1903, Skutezky[17] reports myodegeneration of the heart in 6 cases, of which 5 died; pericarditis, 1 case, with recovery; endocarditis, 15 cases, of whom 6 died; embolism, 3 cases, all ending fatally; thrombosis, 19 cases and 2 deaths.

PNEUMONIA

Pneumonia may not infrequently be a complication of typhoid fever and may be the cause of death during the acute stage, but pneumonia developing some time after recovery can very rarely be attributed to typhoid fever. Bronchitis often associated with typhoid fever may predispose to pneumonia, and if it becomes chronic may end in tuberculosis. Of the cases in Skutezky's series which showed respiratory involvement, bronchitis was the most frequent, and occurred in 38.0% of all cases. Next in order of frequency came laryngitis in 1.5%, and lobar pneumonia in 5.5%, half of which ended fatally. Pulmonary tuberculosis followed in 1.5%, and of these 41.6% died.

True nephritis is considered a rare complication of typhoid fever by Herrick,[18] who quotes Bartels as having seen but 2 instances in 1000 cases. The involvement of the kidneys is usually transient, but during convalescence bacilli are excreted through the kidneys and a nephritis may develop just as

[15] Osler's Modern Medicine, 1907, 2, p. 179.
[16] Am. Jour. Med. Sc., 1904, 127, p. 391.
[17] Ztschr. f. Heilk., 1906, 27, p. 14.
[18] Osler's Modern Medicine, 1909, 6, p. 109.

in any other acute infectious disease. Of Skutezky's cases, 3.2% were complicated by acute nephritis and 38.4% died. Chronic nephritis followed in only 1.01%, with 37.5% mortality. Selby[19] states that albuminuria is not an infrequent accompaniment of typhoid fever, and quotes Stolte as having found this condition in 60% of 371 cases. According to Selby, also, acute parenchymatous nephritis occurred in 3% of Talley's series of 18,000 cases.

From this brief review of the literature it appears that typhoid fever may definitely predispose to tuberculosis. During the acute stages and during the long convalescent period which often follows, the resistance to tuberculosis is lowered. Then, too, under such conditions, a latent tuberculous focus is likely to become active. Just how large a percentage of the tuberculous patients who give a history of typhoid fever actually suffered from typhoid, and the exact relation between the typhoidal attack and the subsequent tuberculosis is difficult to determine. Errors in the diagnosis of typhoid fever are frequently made, and there is still a tendency among physicians to call any continuous indefinite fever, typhoid fever. Such errors of diagnosis are less likely to occur in large cities where laboratory facilities are available.

Respiratory infections are not uncommon complications of typhoid fever and a bronchitis may lead to tuberculosis. That a reduction in the typhoid fever death rate is accompanied by a coincident reduction in the death rate from tuberculosis is indicated by the studies of Woodruff, and the experiences of the U. S. Army and the British Army following antityphoid vaccination. The relation of the 2 diseases is worthy of further clinical investigation.

That the heart and blood vessels are affected in typhoid fever is shown by clinical experience, but the frequency with which permanent damage results is not yet clearly established.

The kidneys may suffer during an attack of typhoid fever as in any of the acute infections; the statistics available are not large enough to determine approximately how often nephritis follows typhoid fever. There is a feeling among medical authorities that true nephritis following typhoid fever is rare.

STATISTICAL STUDIES OF SEVERAL CITIES

A review of the literature indicates an agreement among those discussing the question, that further investigation of the effect of water supply upon diseases other than typhoid fever is necessary. As far as

[19] Am. Jour. Med. Sc., 1908, 135, p. 224.

I am aware, no detailed studies have been made of the mortality statistics of the larger cities extending over a period of years. It therefore seemed desirable to make such a study of several cities where a sudden change had been made from a polluted to a pure water supply to determine whether the Mills-Reincke phenomenon and Hazen's theorem are applicable here as well as in those cities studied by Sedgwick and MacNutt. If the former is based on sound scientific principles, as the authors claim, it should be operative wherever there has been a marked drop in the typhoid fever death rate owing to the substitution of a safe for a polluted water supply. If this phenomenon should be found not to occur in every situation where it might be expected, such a study ought to reveal the reasons.

As examples of cities where a sudden change from a polluted to a pure water supply had been made, Chicago, Cincinnati and Columbus, O., Philadelphia and Pittsburgh have been selected. The detailed mortality statistics for a definite period before and after the change in water supply have been tabulated. Similar figures for New York City and Boston, Mass., covering the same years have served as controls. In addition to a comparison of the crude death rates with the death rates from typhoid fever, malarial fever and diarrhea and enteritis, the death rates of those diseases known to be sequelae of typhoid fever have been especially studied. Curves of the death rates from pulmonary tuberculosis, pneumonia, nephritis and heart disease have also been plotted to see whether during the 3 years immediately following years of high typhoid mortality, there could be demonstrated a sudden rise in mortality from these diseases, a possibility which the data published by Dublin would seem to suggest.

Chicago* made a sudden and radical improvement in its water supply by building the Drainage Canal which reversed the flow of the Chicago River and prevented, to a great extent, the contamination of its water works intakes in Lake Michigan. The canal was opened in 1900. A rapid sand filtration plant was placed into service in Cincinnati in 1908, and in Columbus, during the latter part of the same year. Both Philadelphia and Pittsburgh employ the slow sand filtration process. At Philadelphia, there are 5 separate plants for filtering

* A detailed description of the Chicago water works system and a résumé of its history is given by John Ericson, in the Jour. of the Western Soc. of Engineers, 1913. Similar descriptions of the water filtration plants in the other cities studied are contained in the publications of the respective water works departments, also in a paper by Geo. A. Johnson, "The Purification of Public Water Supplies," Water-Supply Paper No. 315, U. S. Geological Survey, 1913, and Jour. Am. Water Works Assn., 1914, 1, p. 31.

We are concerned, here, only with the method of water purification and the year when it was begun.

Delaware and Schuykill River water. The first of these to be placed in operation was the Lower Roxborough plant, in 1902. Approximately one-half the population was receiving filtered water in 1908. The Queen Lane filters, the last to be constructed, went into service November 29, 1911. The entire city, however, had begun to receive filtered water on February 28, 1909. Pittsburgh began the filtration of its public water supply in November, 1907, and by October of the next year the entire old city, representing about three-fifths of the total population, was using filtered water. The supply was extended to the south side early in 1909, adding less than one-fifth of the population to those already using filtered water. The north side, representing what was formerly the city of Alleghany, and including about one-fourth the entire city's population began to receive filtered water during the latter part of March, 1914.

New York City[20] began the use of chlorination in 1911, but this was only to guard against possible pollution of the Croton supply. During the period 1901 to 1914, inclusive, which has been studied, there have been no striking changes in the typhoid fever death rates. Radical changes were made in the water supply of Boston[21] in 1898, but these were for the purpose of increasing its capacity rather than because of gross pollution. Whatever effect this may have had on the mortality statistics of Boston probably disappeared by 1901, the earliest year employed in the calculations. No marked fluctuations in typhoid fever death rates appear during 1901 to 1914. It may, therefore, safely be assumed that New York and Boston represent suitable controls of the cities which have been studied. The mortality statistics for the various cities studied are contained in Tables 2-13. The statistics, which do not include stillbirths, are taken from corrected mortality statistics, U. S. Bureau of the Census, 1909-1914.

HAZEN'S THEOREM

Table 12 has been compiled from the figures published by the U. S. Census Bureau and the reports of the Chicago health department, and shows the average total number of deaths before and after filtration, and during the first and second periods in the control cities. This was the method employed by McLaughlin, but is only of value when using 1 or 2 years before and after filtration, as a comparison. For example,

[20] Eng. News, 1916, 76, p. 438.

[21] Water Supply and Work of the Metropolitan Water District in the Commonwealth of Massachusetts, 1900.

TABLE 3

DEATH RATES FROM TYPHOID FEVER PER HUNDRED THOUSAND OF POPULATION DURING THE YEARS 1901-1914

City	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Boston.........	23.8	22.1	20.5	23.6	20.8	21.2	10.2	24.7	13.8	11.3	8.7	8.0	8.2	9.0
New York......	20.6	20.3	17.1	16.8	16.0	15.2	17.1	11.9	12.1	11.6	10.9	9.6	7.0	6.3
Cincinnati.....	54.7	61.5	42.2	79.2	40.4	70.2	45.4	18.2	13.3	8.8	11.4	7.7	6.8	6.2
Columbus......	47.4	36.2	36.4	141.4	80.8	35.0	35.8	102.4	19.6	18.1	13.9	19.6	19.1	13.2
Philadelphia...	34.5	47.1	72.3	54.7	50.8	74.3	60.3	35.2	22.3	17.5	14.6	12.8	15.7	7.6
Pittsburgh.....	119.5	136.1	132.7	135.9	106.6	141.1	131.2	48.9	24.6	27.8	25.6	13.1	19.5	15.0

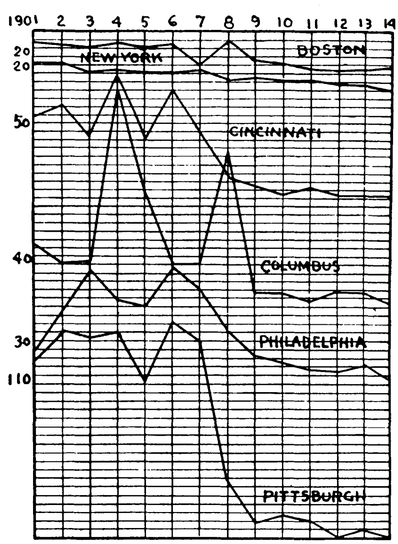

Chart 2. Typhoid fever death rates, per hundred thousand of population. Plotted from Table 3.

TABLE 4

TOTAL DEATH RATES MINUS TYPHOID COMPONENT PER THOUSAND OF POPULATION, DURING THE YEARS 1901-1914, FOR THE CITIES STUDIED, EXCEPT CHICAGO, CALCULATED FROM TABLES 2 AND 3

City	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Boston.........	19.6	18.9	18.1	18.0	18.2	18.3	18.5	18.0	16.6	17.0	16.9	16.2	16.3	16.0
New York......	19.6	18.3	17.7	19.9	18.2	18.1	18.0	16.1	15.8	15.8	15.0	14.3	14.2	14.0
Cincinnati.....	18.9	17.3	18.1	19.7	18.5	19.7	17.6	17.8	16.3	17.2	16.3	16.5	16.8	15.9
Columbus......	13.6	15.1	15.9	14.7	14.0	14.9	15.1	14.1	13.8	15.2	14.1	14.1	15.0	14.6
Philadelphia...	17.6	17.0	18.0	18.1	17.0	18.3	18.0	16.9	16.1	17.2	16.4	15.1	15.5	16.0
Pittsburgh.....	18.0	19.9	19.7	17.9	18.6	18.4	17.9	16.8	15.5	17.6	14.6	15.7	16.9	15.5

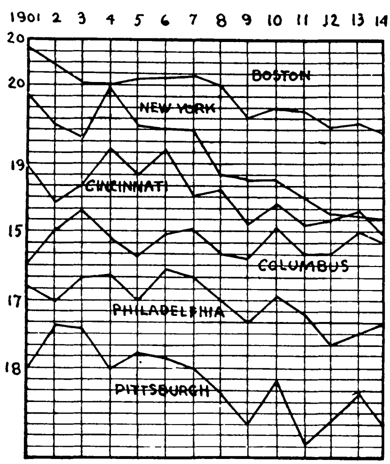

Chart 3. Total death rates per thousand of population, minus typhoid component. Plotted from Table 4.

TABLE 5

DEATH RATES FROM MALARIAL FEVER PER HUNDRED THOUSAND OF POPULATION DURING THE YEARS 1901-1914, FOR THE CITIES STUDIED, EXCEPT CHICAGO

City	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Boston.........	1.6	1.4		0.5	0.5	0.3	1.3	0.5		0.1	0.4	0.1		
New York......	5.0	3.5	2.0	2.7	1.4	1.8	1.7	0.7	0.9	0.7	0.7	0.5	0.3	0.3
Cincinnati.....	4.6	4.2	1.2	0.9	0.6	1.7	0.6	0.8	1.4	0.3	0.5	0.3	0.8	0.7
Columbus......	5.4		1.4	2.8				0.6	0.6		1.1	0.5		
Philadelphia...	1.2	1.5	0.9	1.2	1.3	0.7	0.8	0.7	0.5	0.5	0.7	0.4	0.4	0.5
Pittsburgh.....	2.1	1.7	1.1		1.1		0.8	0.2		0.4		0.4	0.4	

TABLE 6

Death Rates from Diarrhea and Enteritis (Under Two) per Hundred Thousand of Population During the Years 1901-1914, for the Cities Studied Except Chicago *

City	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Boston.........	116.7	106.1	106.4	98.9	108.3	91.1	86.9	112.5	103.9	100.6	106.4	84.8	72.9	64.6
New York......	164.5	134.5	119.8	154.8	151.3	145.8	150.9	137.2	114.8	123.1	92.6	82.4	73.5	67.1
Cincinnati.....	75.3	72.9	74.6	94.8	70.2	104.1	74.7	84.1	78.2	90.1	64.3	67.9	64.5	60.2
Columbus......	35.2	49.5	37.8	55.9	44.7	46.0	49.0	31.1	49.2	63.0	37.4	30.4	41.1	45.5
Philadelphia...	83.3	74.6	90.5	111.3	122.0	150.6	127.7	122.1	117.2	150.3	118.0	93.4	100.6	107.4
Pittsburgh.....	150.6	170.1	195.5	175.1	166.2	191.9	178.0	157.7	139.1	177.3	130.3	113.5	134.8	103.7

* After the second revision of the international classification of causes of death in 1910, the reports from the U. S. Bureau of the Census gave the rates for diarrhea and enteritis under 2, instead of for all ages, as had been done previously. To make the figures comparable, the rates for diarrhea and enteritis under 2, for the years 1901-1909, inclusive, have been calculated from the number of deaths and population statistics contained in these reports.

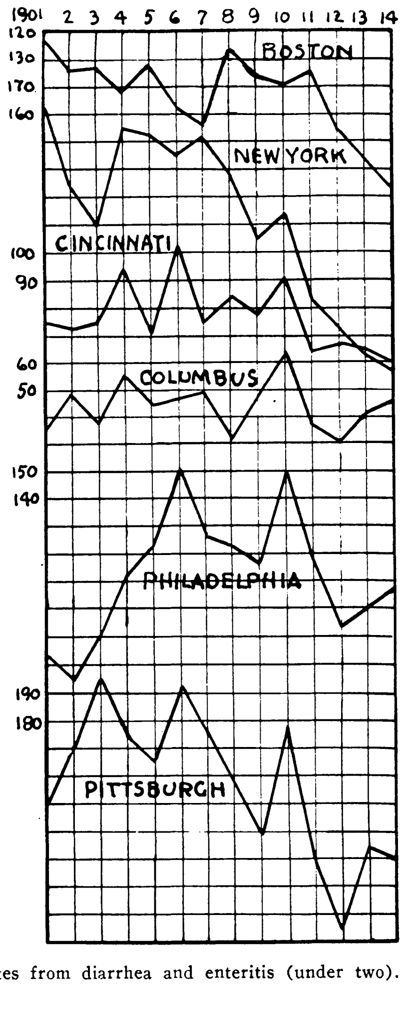

Chart 4. Death rates from diarrhea and enteritis (under two). Plotted from Table 6.

TABLE 7

DEATH RATES FROM PNEUMONIA (ALL FORMS) PER HUNDRED THOUSAND OF POPULATION FOR THE YEARS 1901-1914, FOR THE CITIES STUDIED, EXCEPT CHICAGO *

City	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Boston.........	187.1	194.9	201.7	201.0	194.2	189.4	197.2	180.0	182.0	213.0	207.1	203.1	196.1	190.7
New York......	264.1	264.2	251.2	310.2	232.6	249.1	263.4	204.8	230.7	222.9	209.6	194.7	194.3	180.1
Cincinnati.....	176.3	149.1	160.3	207.9	166.6	165.8	152.9	158.1	143.6	159.5	125.9	153.5	151.3	133.5
Columbus......	105.6	126.3	150.5	141.5	143.6	138.6	133.1	106.1	119.1	135.9	121.2	119.2	113.8	114.4
Philadelphia...	192.3	196.8	182.0	183.7	134.2	161.7	161.0	148.9	138.4	167.1	159.0	133.3	145.4	167.7
Pittsburgh.....	245.5	304.1	267.2	234.8	262.7	244.5	260.3	240.3	252.4	323.7	207.2	261.1	283.3	240.4

* The figures for the years 1901–1909, inclusive, have been calculated from the number of deaths and population statistics as published by the Bureau of the Census.

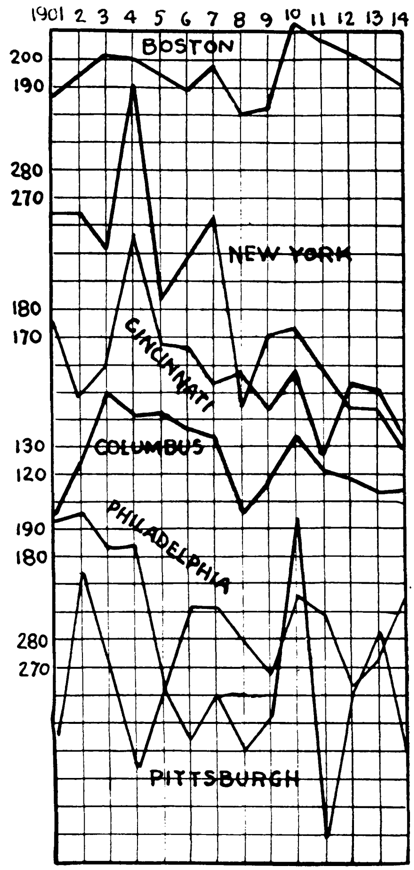

Chart 5. Death rates from pneumonia (all forms). Plotted from Table 7.

TABLE 8

DEATH RATES FROM PULMONARY TUBERCULOSIS PER HUNDRED THOUSAND OF POPULATION FOR THE YEARS 1901-1914, FOR THE CITIES STUDIED, EXCEPT CHICAGO

City	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Boston........	234.4	212.3	205.1	215.8	201.6	195.6	182.9	169.6	158.5	171.7	152.6	152.4	145.5	140.2
New York......	228.8	207.8	211.6	220.4	211.1	214.0	205.8	196.6	185.6	185.0	180.9	173.4	170.1	172.6
Cincinnati.....	235.5	205.5	235.5	265.4	248.0	266.1	231.8	247.1	234.0	261.7	237.0	224.2	229.4	219.8
Columbus......	203.5	191.2	209.7	204.9	189.0	198.7	181.5	172.0	155.3	177.5	159.1	145.5	137.4	137.4
Philadelphia...	210.9	198.4	216.2	230.4	203.4	225.1	220.8	201.7	189.0	193.5	193.5	170.2	165.0	167.7
Pittsburgh.....	129.2	131.0	136.9	149.5	149.1	126.2	112.4	114.2	109.0	104.2	106.0	100.4	106.5	109.2

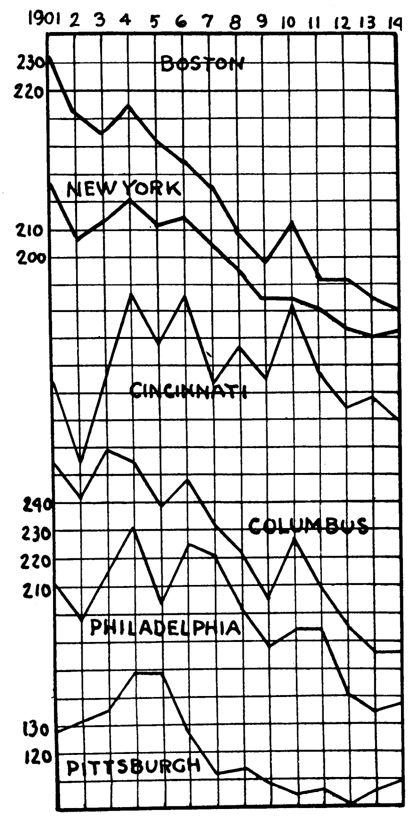

Chart 6. Death rates from pulmonary tuberculosis. Plotted from Table 8.

TABLE 9

DEATH RATES FROM ORGANIC DISEASES OF THE HEART PER HUNDRED THOUSAND OF POPULATION FOR THE YEARS 1901-1914, FOR THE CITIES STUDIED, EXCEPT CHICAGO *

City	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Boston........	179.4	199.0	193.0	191.3	198.5	196.0	210.5	181.2	196.7	201.1	189.9	205.0	211.4	218.7
New York......	130.5	133.9	135.2	155.6	147.9	153.9	158.2	145.7	149.2	137.4	140.1	143.2	144.5	145.8
Cincinnati.....	134.0	145.2	131.4	154.7	151.7	160.7	176.6	170.8	166.1	182.6	185.7	210.6	207.8	191.7
Columbus......	94.1	115.2	107.0	137.3	146.9	127.6	126.2	145.2	165.3	165.5	146.3	159.4	150.9	137.4
Philadelphia...	129.5	142.9	161.5	171.4	165.7	171.2	183.1	166.0	170.8	173.1	181.1	182.1	170.4	196.6
Pittsburgh.....	94.5	91.1	96.6	102.9	110.8	111.8	119.4	114.1	114.5	125.9	118.2	126.8	126.2	118.8

* "Organic Diseases of the Heart" of the reports of the U. S. Bureau of the Census after 1910 corresponds to "Heart Disease," the title in the first revision of the International List of Causes of Death. The former, however, includes International Title 78, "Acute Endocarditis." The figures in the table for 1901-1909, inclusive, represent the rates for the 2 combined as calculated from the number of deaths and population statistics of the reports of the Bureau of the Census.

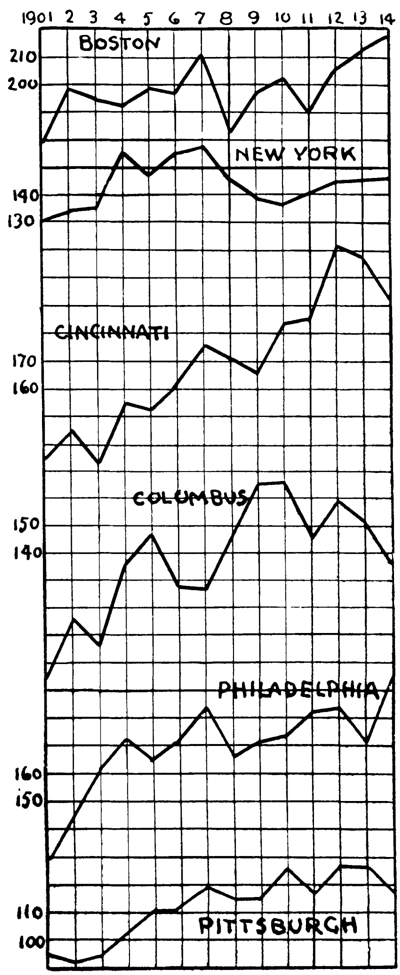

Chart 7. Death rates from organic diseases of the heart. Plotted from Table 9.

TABLE 10

DEATH RATES FROM BRIGHT'S DISEASE AND NEPHRITIS PER HUNDRED THOUSAND OF POPULATION FOR THE YEARS 1901-1914, FOR THE CITIES STUDIED, EXCEPT CHICAGO

City	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Boston.........	82.6	79.0	85.5	81.9	82.6	90.0	86.7	85.6	86.2	89.5	98.9	93.0	91.9	99.5
New York......	162.1	155.4	159.4	171.0	160.5	163.6	164.7	140.9	145.5	142.6	142.8	140.3	138.1	139.0
Cincinnati.....	121.6	116.6	122.8	130.1	121.0	143.0	126.6	125.8	142.2	137.3	144.9	164.1	160.1	145.9
Columbus......	60.4	62.7	74.2	51.7	60.8	75.1	95.5	80.5	81.2	79.5	78.0	79.5	94.3	83.6
Philadelphia...	137.5	135.8	149.3	159.2	164.8	167.6	176.3	159.4	158.9	171.9	164.5	159.5	177.5	174.4
Pittsburgh.....	54.5	63.8	57.2	54.2	59.7	62.3	72.4	70.0	75.1	74.7	73.7	79.7	82.3	88.7

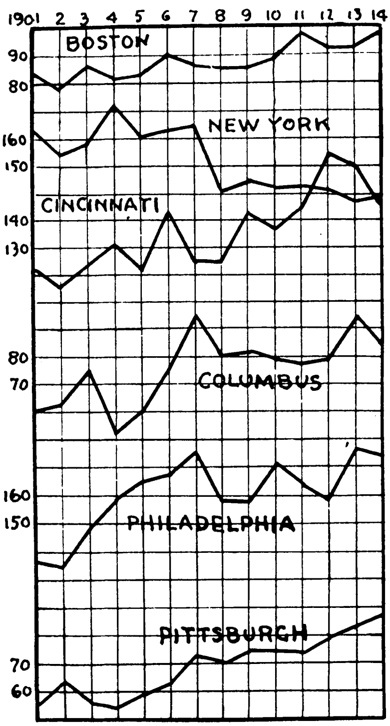

Chart 8. Death rates from Bright's disease and nephritis. Plotted from Table 10.

TABLE 11

TOTAL DEATH RATES PER THOUSAND AND DEATH RATES PER HUNDRED THOUSAND FROM CERTAIN SPECIFIC CAUSES, CHICAGO, FOR THE YEARS 1884-1915 *

Year. Before Opening Canal	Total Death Rates	Typhoid Fever	Total Minus Typhoid	Malarial Fever	Diarrheal Diseases (all ages)	Pneumonia (all forms)	Tuberculosis (all forms)	Heart Disease	Bright's Disease and Nephritis
1884	19.80	56.2	19.24	15.5	307.0	113.2	188.1	61.6	37.0
1885	18.76	74.6	18.02	16.7	254.6	110.7	193.8	69.2	35.3
1886	19.47	68.6	18.79	16.8	240.3	125.1	195.7	64.4	42.6
1887	20.27	50.3	19.77	11.4	268.6	132.6	202.6	72.2	42.1
1888	19.65	46.7	19.17	12.0	253.3	137.7	201.3	77.1	41.1
1889	18.12	48.4	17.64	11.2	251.9	125.0	181.0	71.0	39.9
1890	19.87	91.6	18.96	11.0	242.6	188.5	201.9	74.2	46.3
1891	24.16	173.8	22.43	12.4	273.8	251.8	208.9	80.9	51.7
1892	21.85	124.1	20.61	11.6	233.5	199.8	198.6	88.2	50.8
1893	21.61	53.5	21.08	6.6	260.6	196.1	211.2	88.3	60.1
1894	18.26	37.5	17.89	2.6	270.7	116.1	191.0	79.3	52.0
1895	17.72	37.9	17.35	4.1	217.0	172.6	180.2	99.8	51.3
1896	16.29	52.6	15.77	2.2	206.9	150.0	186.8	90.3	57.3
1897	14.63	29.3	14.34	1.6	165.3	144.3	172.6	91.6	62.8
1898	14.64	40.8	14.24	1.7	142.8	159.1	181.7	89.8	67.5
1899	15.68	27.2	15.41	1.5	154.8	211.4	178.9	91.7	72.6
Canal opened 1900.									
1900	14.68	19.8	14.49	1.7	130.6	199.5	173.9	111.4	65.7
1901	13.93	29.1	13.64	1.3	126.3	178.5	164.0	111.1	57.9
1902	14.69	44.5	14.25	1.2	123.6	190.6	165.4	116.5	69.8
1903	15.62	31.8	15.31	1.1	118.4	250.1	182.5	113.0	81.9
1904	13.85	19.6	13.66	0.3	110.8	217.8	186.5	107.5	97.3
1905	13.96	16.9	13.80	0.8	129.1	184.1	188.8	108.3	103.5
1906	14.54	18.5	14.36	0.4	113.1	202.5	192.0	109.8	106.5
1907	15.72	18.2	15.54	0.3	119.6	232.1	197.2	113.2	121.9
1908	14.49	15.8	14.34	0.5	146.6	167.4	186.7	128.1	102.0
1909	14.58	12.6	14.46	0.4	145.1	219.6	181.0	147.4	105.9
1910	15.14	13.7	15.01	0.5	159.8	240.8	178.0	151.4	113.9
1911	14.49	10.7	14.39	0.4	132.8	219.5	165.9	152.9	109.5
1912	14.83	7.6	14.76	0.2	133.9	213.1	163.9	152.0	103.5
1913	15.06	10.6	14.96	0.3	137.1	207.6	164.9	147.8	99.1
1914	14.19	6.9	14.13	0.4	126.5	170.3	163.2	162.9	83.8
1915	14.18	5.4	14.13		106.5	155.8	170.3	158.6	88.0

* Figures copied from chronological summaries of mortality statistics in the annual reports of the Department of Health of the City of Chicago for the years 1906, 1907–1910 and Bulletin Chicago School of Sanitary Instruction, February 5, 1916. Malaria figures after 1906 are from reports of the Bureau of the Census. Total minus Typhoid Rates are calculated from Columns 1 and 2.

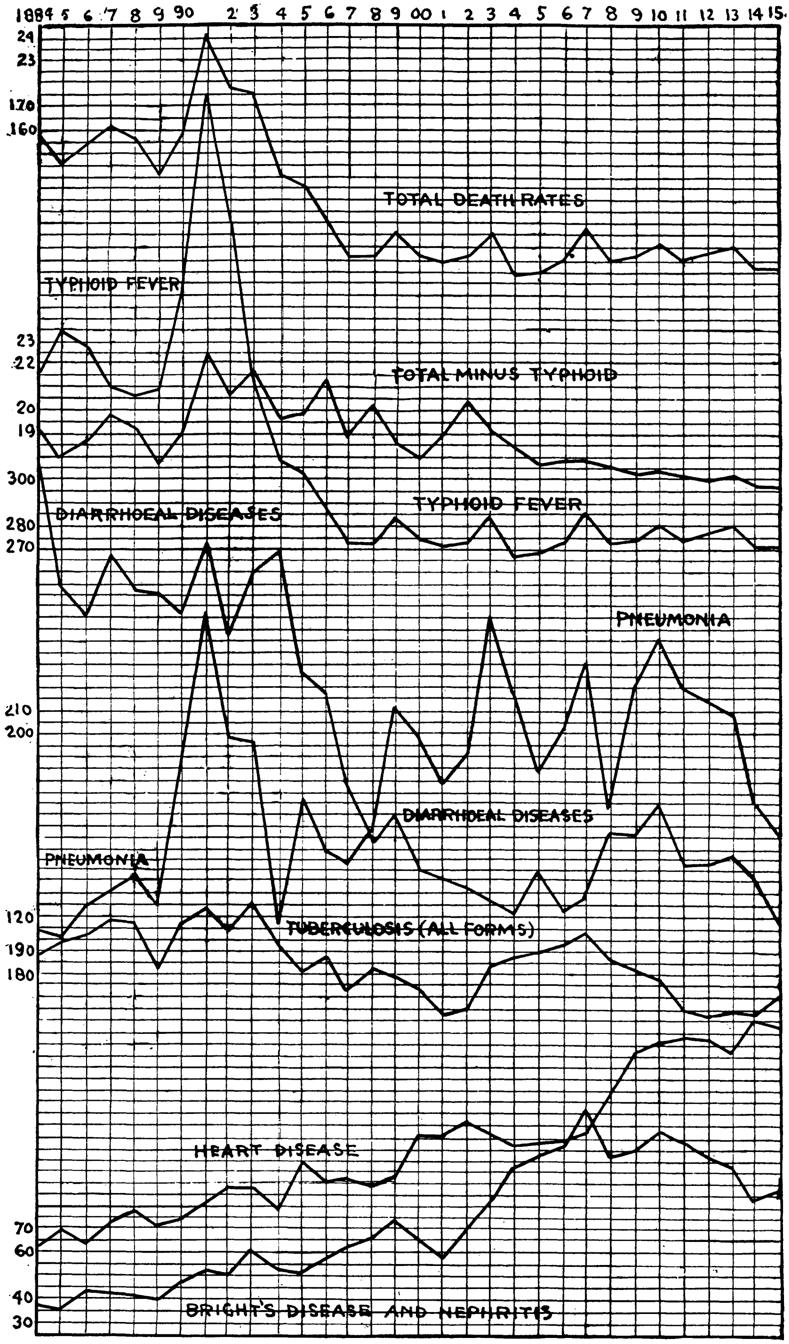

Chart 9. Total death rates per thousand and death rates per hundred thousand, froı certain specific causes, Chicago, during the years 1884-1915. Plotted from Table 11.

TABLE 12

AVERAGE TOTAL NUMBER OF DEATHS IN THE CITIES STUDIED, AND AVERAGE NUMBER OF DEATHS FROM TYPHOID FEVER AT PERIODS INDICATED

City		Total Deaths	Typhoid Fever
Boston	First period	11,114	119
	Second period	11,635	81
	Increase	521	Decrease 38
New York	First period	73,379	684
	Second period	74,563	482
	Increase	1,184	Decrease 202
Chicago	Before canal opened	20,697	499
	After canal opened	28,189	347
	Increase	7,492	Decrease 152
Cincinnati	Before filtration	6,562	192
	After filtration	6,364	38
	Decrease	198	Decrease 154
Columbus	Before filtration	2,233	85
	After filtration	2,735	52
	Increase	502	Decrease 33
Philadelphia	Before filtration	25,661	791
	After filtration	25,877	280
	Increase	216	Decrease 516
Pittsburgh	Before filtration	9,444	610
	After filtration	8,892	134
	Decrease	552	Decrease 476

Calculated from mortality statistics published by U. S. Bureau of the Census, except in the case of Chicago which were obtained from the publications of the Chicago health department.

there were 7,492 more deaths after the opening of the Drainage Canal in Chicago than there were during a corresponding period before. The reasons for this large increase are that the periods under consideration are long, and include years of rapid increase in population, no account of which is taken in calculating the total number of deaths.

The figures, bearing in mind the objections mentioned, show that there has been an increase in the average total number of deaths during the second period in all the cities except Cincinnati and Pittsburgh. This is to be expected because of a steady increase in population in such large cities. The increase has been greatest in New York, the city with the largest population. The data for Chicago are not comparable with the others, because they cover a much longer period. The

smallest increase occurred in Philadelphia. Pittsburgh shows a remarkable decrease, amounting to more than the increase in Boston. No explanation can be attempted without a study of the specific death rates. The decrease in Cincinnati is only slightly greater than the number of deaths less from typhoid fever.

The decrease in the number of deaths from typhoid fever is of interest. It is greatest in Philadelphia, and yet Philadelphia did not have nearly as high a typhoid fever death rate before filtration as Pittsburgh, and a lower average rate than Cincinnati and Columbus. New York, without a sudden or radical change in its water supply, avoided more deaths from typhoid fever than any of the other cities, except Philadelphia and Pittsburgh. Among all the cities, there is considerable difference in population, and the only fair comparison would be one of rates per 100,000. This method of calculation is open to grave sources of error even in comparing the year before filtration with the year immediately following, in that either may easily happen to be a year containing an unusually large number of deaths from accidental causes, or from an epidemic of one of the infectious diseases such as influenza or pneumonia. In either case, the results would be misleading.

Table 13 shows the average total death rates and the death rates from certain specific diseases during the period before improvement of the water supply, in those cities where such an improvement was made, and for a period covering the same years in the control cities, compared with the corresponding average for a similar period following the change in water supply, and the same period in the control cities. This table was calculated from the data contained in Tables 2-11.

For Boston, the reduction in the total death rate during the second period under consideration has been 1.8, while the reduction in the typhoid fever mortality has been 0.08 per 1000, showing that for every death less from typhoid fever in Boston there have been approximately 22 deaths less from other causes. In New York, the reduction in total mortality compared with the reduction in typhoid mortality is about 51 : 1. During the period following the improved water supply in Chicago, the reduction in the general death rate was 3.6, while the reduction from typhoid fever was 0.07 per 1000, giving a saving of about 13 lives from other causes to every death less from typhoid fever. The data for Chicago cover a much longer period than those of the other cities, and it is probable that the figures for a shorter period would have shown a smaller reduction in the general death rate and a

greater reduction in the typhoid fever rate, making the relative number of deaths avoided from other causes lower. Cincinnati shows a reduction in total mortality of 2.3 per 1000, and a reduction in typhoid mortality of 0.45, indicating that for every death from typhoid fever

TABLE 13

AVERAGE TOTAL DEATH RATES PER THOUSAND, AND AVERAGE DEATH RATES PER HUNDRED THOUSAND OF POPULATION FROM CERTAIN SPECIFIC DISEASES FOR THE CITIES STUDIED *

City	Total Death Rates	Typhoid Fever	Malarial Fever	Diarrhea and Enteritis	Pneumonia	Tuberculosis	Heart Disease	Nephritis
Boston	18.7 16.9 1.8	20.3 11.9 8.4	0.8 0.1 0.7	102.0 92.2 9.8	180.8 196.0 15.2†	206.8 155.8 51.0	195.4 200.5 5.1†	84.0 92.1 8.1†
New York	18.8 15.2 3.6	17.6 9.9 7.7	2.6 0.6 2.0	145.9 98.7 47.2	262.1 205.3 56.8	214.2 180.6 33.6	145.0 143.7 1.3	162.4 141.1 21.3
Chicago	18.8 14.6 4.2	50.8 17.5 33.3	8.7 0.6 8.1	221.5 120.6 100.9	158.4 203.1 44.7†	192.1 114.0 78.1	80.6 130.7 50.1†	50.6 94.4 43.8†
Cincinnati	19.1 16.8 2.3	56.2 10.3 45.9	1.9 0.8 1.1	80.9 72.7 8.2	168.4 146.5 21.9	241.1 236.1 5.0	150.6 187.9 37.3†	125.9 145.6 19.7†
Columbus	15.3 14.7 0.6	64.4 17.2 47.2	1.3 0.4 0.9	43.6 44.4 0.8†	130.6 120.6 10.0	193.8 152.0 41.8	124.9 154.1 29.2†	70.1 82.7 12.6†
Philadelphia	18.3 16.4 1.9	54.8 17.9 36.8	1.1 0.5 0.6	108.5 114.1 5.6†	173.1 151.4 21.7	215.0 182.9 32.1	160.7 177.1 16.4†	155.8 166.6 10.8†
Pittsburgh	19.8 16.3 3.5	129.0 24.9 104.1	0.9 0.2 0.7	175.3 136.6 38.7	259.9 258.3 1.6	133.4 107.0 26.4	103.8 120.6 16.8†	60.6 77.7 17.1†

* The first row of figures represents the period before filtration or change in water supply in those cities where such a change was made, and for the first half of the period under consideration in the control cities. In the second row are the figures for the second period, while the third row represents the difference. The classification of diseases corresponds with that in Tables 2-11.

† Represents an increase. All other third row figures indicate a decrease. Calculated from Tables 2-11.

avoided there have been approximately 5 lives saved from other causes. During the period following filtration in Columbus, there has been a reduction in the general mortality amounting to 0.6 per 1000, while the

reduction in typhoid mortality has been 0.36, or a saving of less than 2 lives from other causes for every 1 from typhoid fever. Columbus has had a low general death rate throughout the entire period before and after filtration. In Philadelphia, the reduction in the total death rate after filtration was 1.9 per 1000, while the reduction in the typhoid fever rate was 0.36, indicating that for every death avoided from typhoid fever, about 5 deaths from other causes have been avoided. The reduction in total death rate in Pittsburgh following filtration was 3.5 per 1000, and the reduction in typhoid fever rate was 1.04, so that for every death avoided from typhoid fever about 3 deaths from other causes have been avoided.

A comparison of the figures shows that in those cities where a sudden change has been made from a polluted to a pure water supply, the reduction in the general mortality compared with the reduction in typhoid mortality varies from 2:1 to 13:1. In Boston, the ratio was 22:1, and in New York, 51:1. The comparative reduction was 4 times as great in New York, one of the control cities, as in Chicago, where the greatest reduction occurred among the cities with an improved water supply. The comparison, however, is neither fair to New York or the other cities. The figures for Chicago cover a period of 32 years, during which there has been a gradual reduction in the general death rate, while the figures for New York and the other cities cover only a period of 14 years.

In both control cities there has been a gradual reduction in the general death rate, which compares favorably with the reductions observed in those cities which have made a sudden improvement in their water supplies. The average reduction in New York was greater than in any of the other cities except Chicago, and the figures of the latter include a much longer period. The average reduction in Boston was greater than in Columbus. Yet neither New York nor Boston made radical changes in its water supply during the periods under consideration. The average typhoid fever death rates in the control cities during the second period are less than the average rates in any of the other cities during the period following improvement in water supply, with the exception of Cincinnati which is lower than Boston. It is therefore evident that in the control cities without a marked reduction in typhoid mortality there was, however, a reduction in the general mortality exceeding, in some cases, the reduction shown by cities which had made a sudden change from a polluted to a pure water supply.

THE MILLS-REINCKE PHENOMENON

In considering the reduction from specific diseases, the reduction in the death rates from typhoid fever is the most marked and most constant. Detailed studies are already on record for the various cities under consideration and have demonstrated the relation between high typhoid incidence and polluted water supply. The greatest average reduction occurred in Pittsburgh; the smallest, in Chicago. It is of interest to note that of the 5 cities studied, Cincinnati has the more closely approached the 'residual' rate as shown by Boston and New York during the period following filtration.

During the second period in Chicago, the death rate from 'reported' malaria, which was high for a nonmalarial region, was reduced to a rate equal to that in New York. In the other cities, the reductions are no more striking than in the controls.

Diarrhea and enteritis under 2, show a fall in every case except Columbus and Philadelphia. In Boston, the reduction has been slight. New York, without a radical change in its water supply, shows a greater reduction in its rate from diarrhea and enteritis than any of the other cities with which it is comparable.

It is difficult to obtain a comparable set of statistics for pneumonia, since the question of diagnosis as well as the age distribution of the population are important factors in determining the death rate. Changes in classification of the causes of death also affect the figures for pneumonia. The statistics, which include those of all forms of pneumonia, show that there has been an appreciable reduction in Columbus, Philadelphia, and New York; a decrease not nearly so large in Cincinnati, practically no reduction in Pittsburgh, and a definite increase in Boston. In this case, one of the control cities shows the most marked decrease, while the other shows the greatest increase. Such differences are to be explained by the differences in age and sex distribution of the population.

The greatest average reduction in pulmonary tuberculosis occurred in Boston. New York shows a greater reduction than Philadelphia and Pittsburgh. Cincinnati showed very little reduction during the period following filtration, and a much higher average rate during the second period than any of the other cities studied. In Columbus and Philadelphia, the reduction in the death rate from pulmonary tuberculosis has been nearly as great as that of typhoid fever.

There has been a general tendency for the death rate from pulmonary tuberculosis to decline, but it should be emphasized that the

average reduction in the control cities is as marked as in any of the cities which have improved their water supply, and greatly exceeds the reduction in one or two of them.

During the periods compared, every city but New York shows an increase in the average death rate from nephritis. The latter, with an excessive rate for the first period, shows a reduction during the second period. The lowest rates are found in Boston, Columbus, and Pittsburgh, while Cincinnati and Philadelphia show a high average rate which is slightly on the increase.

The death rates from heart disease show an increase in every case but New York, the greatest increase having occurred in Cincinnati.

The data for Chicago require separate consideration, because of differences in classification of one or two diseases, due to the fact that the statistics have been obtained from different sources.

Chicago shows a greater reduction in total death rate than any of the other cities because of the longer period involved in the calculations, and yet the reduction in typhoid mortality is no more striking than in Philadelphia, and much less than in Pittsburgh, while both Cincinnati and Pittsburgh have made greater reductions. Diarrhea and enteritis includes all ages for Chicago, and this accounts for the difference in rates. For all forms of pneumonia, Chicago shows the largest increase, which is almost equal to the reduction occurring in New York. Tuberculosis shows the greatest decrease of any of the cities considered because of the longer periods and because all forms of tuberculosis are included. The average death rate from heart disease shows a greater increase than in any of the other cities. Differences in classification enter here in addition to the factors already mentioned. The same is true of nephritis with the exception of the question of classification.

Thus far, the data show that in those cities which have made a sudden improvement in their water supplies, the only change in the death rate from any cause which can be attributed directly to the change in water supply is found in the typhoid fever rate. Among the other causes of death studied, changes equally marked, have occurred in control cities.

THE SEQUELAE OF TYPHOID FEVER

A study of the curves of mortality shows that in Chicago, the years of highest typhoid incidence were 1891 and 1892. During the years 1890-1894, the typhoid fever curve follows closely that of pneumonia,

the point of highest mortality occurring the same year in both. Beyond that, the peaks correspond rather closely, the pneumonia peak of 1905 coming one year after a similar typhoid peak.

Following the high typhoid rate of 1885, there is a gradual rise in the death rate from all forms of tuberculosis which continues until 1889, the greatest rise occurring in 1886. However, the curves for pneumonia, heart disease and nephritis show almost identical courses for the same period, in addition to which there are several infectious diseases predisposing to tuberculosis, the curves of which have not been plotted. In 1893, 2 years after the biggest typhoid year in Chicago, there is a distinct peak in the death rate from tuberculosis.

The curve of heart disease shows a gradual rise with irregular peaks, which is permanent and seems to bear no relation to the typhoid curve. The year 1893 shows a distinct peak in the curve of mortality from nephritis which is 2 years after the year of greatest typhoid mortality and corresponds with a similar peak in the tuberculosis curve. However, the nephritis rate shows an irregular increase up to the year 1906, after which it began to decline slowly. The curves for Chicago are of particular interest, covering as they do, a period of 32 years.

The years of epidemics of typhoid fever in Cincinnati were 1904 and 1906. There is a corresponding peak in the pneumonia curve during 1904, but a drop in 1907. Pulmonary tuberculosis shows peaks corresponding to those of typhoid fever during epidemic years, and also one in 1908, 2 years following the last typhoid peak. The rise in 1910 does not seem to bear any relation to the typhoid fever rate. Heart disease shows a jump in 1907, the year following the last typhoid peak, but in general the 2 curves show no similarity. The curve for nephritis contains peaks in the 2 high typhoid years and after the second one there are 2 additional peaks, 3 and 6 years later.

In Columbus, the years of epidemic typhoid were 1904 and 1908. There is a peak in the pneumonia curve in 1903, the year before the first high typhoid year, and one in 1910, 2 years after the second. Pulmonary tuberculosis shows a high rate during the same year as the first typhoid peak, and a similar one 2 years later. In 1910, 2 years after the second high typhoid year there is a third rise in the death rate from pulmonary tuberculosis. The maximum of 2 periods of increase in the death rate from heart disease is reached in the year following each of the years of high typhoid mortality, but these began the year before in both cases. Nephritis shows a peak in the years pre-

ceding each of the 2 high typhoid years. There is a third peak in 1913, 5 years after the last epidemic year.

The 2 years of highest typhoid mortality in Philadelphia were 1903 and 1906. No points of similarity appear between the typhoid curve and the curve of pneumonia. There is a peak in 1910, 4 years after the second high typhoid year. Pulmonary tuberculosis shows a peak in the year following the first typhoid peak and one the year after the second. The curve of mortality from heart disease shows a sharp rise in each of the years following the 2 years of high typhoid mortality. There are 3 distinct peaks in the nephritis curve, one each in 1907, 1910, and 1913. These are 1, 4, and 7 years after the second point of high typhoid mortality.

Pittsburgh, before filtration, had an excessively high typhoid fever rate, with no distinctly epidemic years. There are no points of similarity or relationship between the typhoid and pneumonia curves. The death rate from pulmonary tuberculosis begins a sharp decline the year before the fall of the typhoid curve. The curve for heart disease rises somewhat irregularly, more so after filtration of the water supply was begun, but bears no relation to the typhoid curve. The same is true of nephritis.

Charts 1 and 3 show that the mortality from typhoid fever has little influence on the total death rates, since the outlines of the curves on both charts are alike. Were this not so, the control cities might be expected to show similar curves of total death rates and death rates minus typhoid fever, while the cities with polluted water supplies ought to show curves more nearly resembling those of typhoid fever before filtration.

Diarrhea and enteritis under 2 years, the only water-borne disease in addition to typhoid fever which has been charted, shows that in Boston and New York there is no similarity between the 2 curves. In Cincinnati, however, the curves have practically the same outline with corresponding years of high incidence. There is only one corresponding peak in the curves of typhoid fever and diarrhea and enteritis in Columbus, and the sharpest rise, in 1910, occurs in a low typhoid year. Diarrhea and enteritis show only 1 peak corresponding to a high typhoid year, in 1906. The high rate of 1910 finds no corresponding high rate in typhoid fever. The curve for diarrhea and enteritis in Pittsburgh shows that the years 1903, 1906, and 1910 were years of high death rates. The first 2 are also years of high typhoid mortality,

while the last is not. The year 1910 shows a high mortality from diarrhea and enteritis in children in all the cities for which curves have been plotted, which makes it appear that some common factor, other than polluted water is involved, since during that year all the cities under consideration were supplied with unpolluted water.

The curves of mortality for Chicago require separate consideration, because of the longer periods studied and because of differences in classification. Here as well as in the other cities, the total death rate minus the typhoid component shows that typhoid mortality does not influence the course of the general mortality to any appreciable extent. The year 1891, which was a year of high typhoid mortality, shows high rates from diarrheal diseases, pneumonia and total tuberculosis in addition to an exceedingly high typhoid mortality. What part the sewage polluted water supply played in this high mortality other than in the case of typhoid and diarrheal diseases it is impossible to say without a consideration of all the factors involved. The years of greatest typhoid mortality in Chicago were 1890, 1891, and 1892. Diarrheal diseases show high rates in 1891, 1893, and 1894, in the production of which impure water supply probably played a considerable part. During the high typhoid years there are correspondingly high rates for pneumonia and all forms of tuberculosis. The latter showing an additional peak in 1893, the year after the last high typhoid year, while pneumonia has a marked rise during the next year.

Heart disease and nephritis show a gradual rise in mortality from the beginning without demonstrable relation to the typhoid mortality. Since 1907, nephritis presents a curve resembling that of typhoid fever, which is declining more rapidly than the latter.

GENERAL DISCUSSION

There are 2 factors which determine the ratio between the reduction in total mortality and the reduction in typhoid fever mortality. One is the rate at which the general mortality is being lowered, and the other is the height of the typhoid fever rate before filtration and the proportion due to water-borne infection. The curves of total death rate and total death rate minus typhoid component show that typhoid mortality does not greatly influence the course of the total death rate. The latter, especially in large cities, may show fluctuations quite independently of water supply, and being the resultant of a multiplicity of components, it is extremely difficult to establish its relation to a polluted

water supply. The death rate from typhoid fever is a factor which varies with each individual city and is also one of the components of the general death rate, although not a numerically important one as the curves show.

Although water is the most important source of infection in typhoid fever and the water-borne diseases generally, other articles of diet and carriers, especially, are also concerned in their dissemination. An improvement in the milk supply may lead to a decrease in the death rates from typhoid fever and other intestinal infections quite as striking as that following a sudden change in water supply. That the incidence of diarrhea and enteritis is excessively high in a city having a polluted water supply, there can be no doubt, for at least some of the infectious diarrheas in children are water-borne. Exactly what effect purification of a water supply has on the death rate from this class of diseases is difficult to determine, even by a detailed study in each instance. The proportion of diarrhea and enteritis in children due to infection is still a matter of discussion, and among the infectious diarrheas several organisms have been held to be the cause. Typhoid fever in infants is probably more common than is generally believed. In a recent study of typhoid mortality and morbidity in Pennsylvania during 1910, 1911, and 1912, Freeman[22] found 1623 cases and 194 deaths in children under 5 years. Without doubt, many more unrecognized cases occurred. In looking over the literature, one is struck by the fact that, about 25 years ago, cases of typhoid fever in infants were rarely recognized. Within the last few years the number of cases reported has markedly increased. A part of the reduction in diarrheal diseases is no doubt due to the disappearance of wrongly diagnosed typhoid cases.

Other factors may be of equal importance in bringing about a lowered mortality, aside from purification of the water supply. It is obvious that coincident improvement in both water and milk supplies would result in greater reduction in mortality than either alone. It would just as obviously be wrong to attribute the total effect to improvement in water supply. Landis[23] on the basis of his experience in Cincinnati before and after efficient milk inspection, as compared with filtration of water supply, believes that in communities which effectively purified their milk supplies the reduction in the general death rate is practically equal to that following a change from a polluted to a pure water supply. It may even be greater, since, in addition to being

[22] Pub. Health Rep., 1916, 31, p. 3356.
[23] Cincinnati Department of Health, Annual Report, 1915.

a vehicle for the transmission of the water-borne diseases, milk may serve as the medium of spreading certain other diseases through the agency of human carriers (diphtheria, scarlet fever, septic sore throat) If the drop in rates following water purification be ascribed to this change, it is just as logical to attribute any increases to the same cause.

Viable tubercle bacilli have been found in sewage-polluted streams. The extent to which tuberculosis of the intestinal tract and bone and joint tuberculosis are due to infected water is probably small. Of greater importance is the use of milk from tuberculous cows without proper pasteurization.

All public health activities are tending to lower the general death rate and lengthen the average duration of life. This results in an increase in the number of people of an age when pneumonia and the cardiorenal diseases become natural causes of death. In other words, some of those saved from an early death of infectious disease later die of the degenerative diseases. This is, therefore, one of the factors tending to increase the mortality from these diseases. To this may be added the number of deaths occurring as a sequel to typhoid fever. Among the factors tending to decrease their mortality are the education of the masses in the importance of mouth hygiene and focal infection, and a smaller number of people suffering from typhoid fever, because of improvement in water supplies and other public health activities. The relative importance of the latter is difficult to determine, but it is probably of less influence than the others mentioned. The numerous factors involved obscure the results of any study of this point.

The effect of changes in classification of causes of death upon mortality statistics is very well illustrated in the case of heart disease. "Organic diseases of the heart" of the second revision of the International List of Causes of Death includes "heart disease" and "acute endocarditis" of the first revision. The discussions in the reports of the Bureau of the Census warn against comparing statistics of heart disease before and after the second revision without taking into account the differences due to the change in classification. Yet such figures have been used to prove an undue rise in mortality from this cause since 1910.

It has been suggested that the use of a pure water supply leads to an increased resistance to infection. The facts that bacteria are constantly ingested with food, and that the intestinal mucosa normally contains a rich flora, would seem to indicate that the intestinal mucosa

has developed a high natural resistance against the ordinary organisms. The specific bacteria producing intestinal lesions are presumably absent from a pure water supply, and this is probably the most important result of purification. On the other hand, there develops among the users of an impure water supply a proportion of individuals who are resistant to water-borne infection. Those accustomed to the use of a pure water supply often become easily infected when in a community supplied with polluted water. Whether the great majority of the population uses water more freely after it has been purified is doubtful. With the exception of fondness for liquid foods and soft drinks, water intake is under the control of a reflex physiological mechanism and is not subjectively influenced.

It is not intended to minimize the importance to a community of constantly maintaining a high degree of purity in its water supply. The number of lives saved from typhoid fever alone, without consideration of the loss of time and cost of medical attention during illness and the effects of the possible sequelae of typhoid fever, would more than justify any expenditure to bring this about. I wish merely to emphasize the importance of other factors which may influence the reduction of mortality, general and specific, following improvement in water supply.

SUMMARY AND CONCLUSIONS

In an analysis of the mortality statistics of several cities which had made a sudden and radical change from a polluted to a pure water supply, over a period before and after improvement, no striking evidence has been found that the Mills-Reincke phenomenon and Hazen's theorem apply to these cities, when compared with control cities. The figures indicate a great variation among the cities studied, including the controls. There is, therefore, a lack of uniformity in the appearance of the Mills-Reincke phenomenon and Hazen's theorem, since some of the cities thus far studied apparently show an increase, while others show a reduction in general death rates following improvement in water supply. This is to be expected because of the numerous factors affecting the general and specific death rates.

It is extremely difficult, if not impossible, to determine the exact relation between a reduction in typhoid fever mortality and the reduction in mortality from other diseases. In the case of malarial fever, Table 5 and Chart 9 show that during high typhoid years in those cities having an impure water supply, there is in general a rise in mortality

from malaria. Following improvement in the water supply, the mortality from malaria falls to a minimum. Inaccuracy of diagnosis probably accounts for this change.

Clinical evidence indicates that pulmonary tuberculosis, pneumonia, and cardiorenal diseases may follow or complicate typhoid fever as well as any of the other infectious diseases, but a study of the mortality statistics fails to bring to light any effect of a high typhoid death rate on the death rates from these diseases. It is difficult to follow 1000 recovered cases of typhoid fever and be sure that any of the sequelae developing in later years are due to the attack of typhoid fever or to some other cause. It is infinitely more difficult to trace the direct effect of the typhoid fever death rate upon the death rates from the sequelae of typhoid fever in large cities. Even if it be assumed that tuberculosis, pneumonia, nephritis or heart disease follows in 5% of the recovered cases of typhoid fever, it would still be necessary to consider the effects of all the other infections, some of which are much greater than those of typhoid fever, before any conclusions could be drawn as to cause and effect.

The total death rate shows a tendency to decline in all the cities studied. In the control cities, the average reduction during the second period has been more marked than in some of the cities which improved their water supplies. Thus, Boston shows a greater average reduction than Columbus; while New York shows a greater average reduction than any of the other cities with which it is comparable.

The death rates from pulmonary tuberculosis also show a general tendency to decline. This tendency is more marked in the control cities than in most of the cities which have improved their water supplies. The percentage of tuberculous infection due to sewage-polluted water can at best be only very small, and its disappearance from the death rates would not produce a marked change.

The death rates from pneumonia are quite irregular, but with a general downward tendency, except in Pittsburgh. This is equally marked in the control cities.

The death rates from nephritis show a gradual rise, except in one of the control cities, New York. No changes appear which are unique for the cities with improved water supplies. The curve for heart disease also shows a decline in New York, while in the other cities there is a rise.

Considering the diseases that are sequelae of typhoid fever, as a whole, there is a general tendency toward an increase, but this is not peculiar to the cities which have had excessive typhoid fever rates.

There can be no doubt that an impure water supply may be and, in general, is accompanied by a high general death rate. Because of the multiplicity of factors involved, it is not possible to determine the exact relation between the two by a study of the general mortality statistics. Some cities will of necessity show a decrease, while others may even exhibit an apparent increase in mortality.

That a high typhoid incidence tends to increase the number of deaths from the sequelae of typhoid fever must also be true. But the large number of other factors tending to produce the same effect makes the problem very complicated, and one that probably cannot be solved by any comparison of mortality statistics.

The use of suitable controls is indispensable in studying special phases of the mortality of large communities.